SFB 917

JARA|FIT Fundamentals of Future Information Technology

Scalability of EUV interference lithography to sub-10 nm half pitch

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Motivation

Lithography has been in a challenge to bring the resolution down to 10 nm level. Self-imaging Talbot lithography is a promising candidate for the high resolution printing. However as the size of structures on the mask approaches the wavelength of the radiation, diffraction influence needs to be evaluated precisely to estimate the achievable resolution and quality of the patterns.
Here we present the results of FDTD simulation of the diffraction on EUV transmission masks in dependence on period (pitch) of the mask, with the aim to determine the resolution that can be realistically achieved with the EUV Talbot lithography.
Additionally, latest experimental achievements of laboratory-based EUV Talbot lithography are reported.

Introduction and Principle

Talbot effect is a well-known physics phenomenon in which illuminated objects with periodic transmission profile produce self-images [1], [2], [3].
With **monochromatic wave**, a periodic Talbot self-image formed by a line grating with a pitch d appears at distance z_T.

$$z_T = \frac{\lambda}{1-\sqrt{\left(1-\lambda^2/d^2\right)}} \approx \frac{2d^2}{\lambda}$$

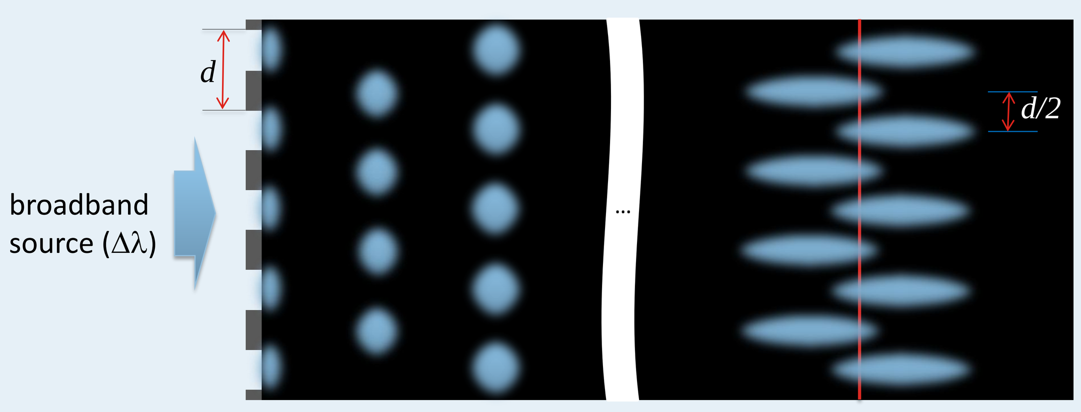
Maximal intensity with period d is observed at intervals $z_T/2$ in propagation direction alternately shifted for half of the period perpendicular to propagation axis.

With **broadband spectrum**, Talbot self-images of each wavelength mix in the propagation direction and form a stationary image.

Maximum intensities in x-axis are produced with **half of the period (d/2)** of the grating object at z_M with broadband spectrum.

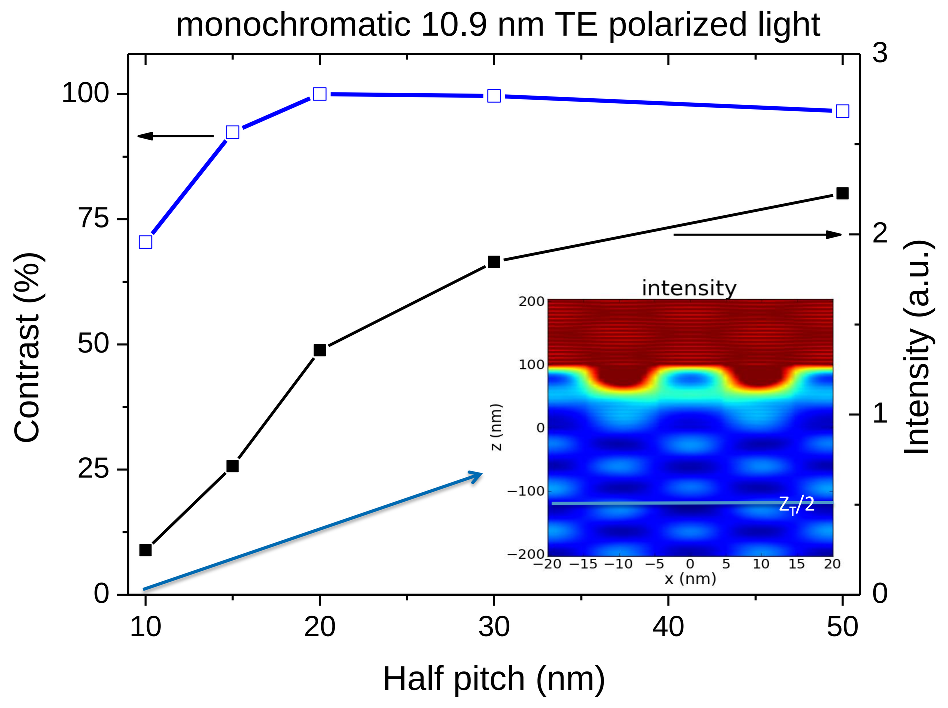
$$z_M = \frac{2d^2}{\Delta\lambda}$$

$\Delta\lambda$: bandwidth
Ref. [4]



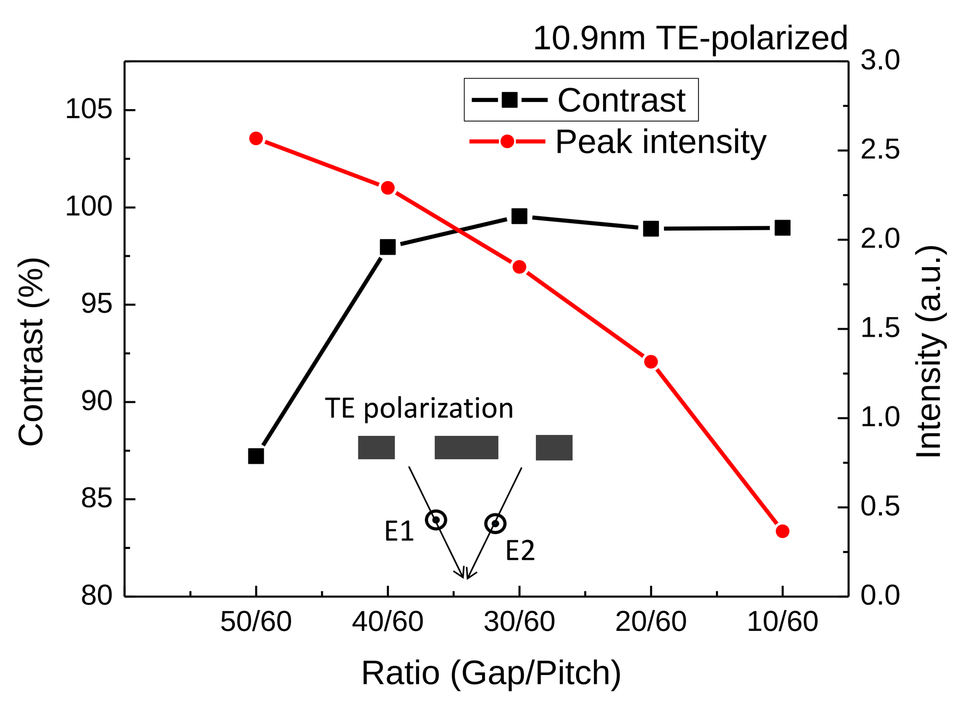
Talbot self-images with monochromatic wave

- Wavelength: 10.9 nm
- Space to line ratio: 1:1
- Gratings half pitch 10 - 50 nm
- Intensity and contrast are shown at $z_T/2$.
- Ni absorber with 100 nm thickness
- Simulated by FDTD method



- Maximal contrast and peak intensity are decreasing faster below 20 nm half pitch.

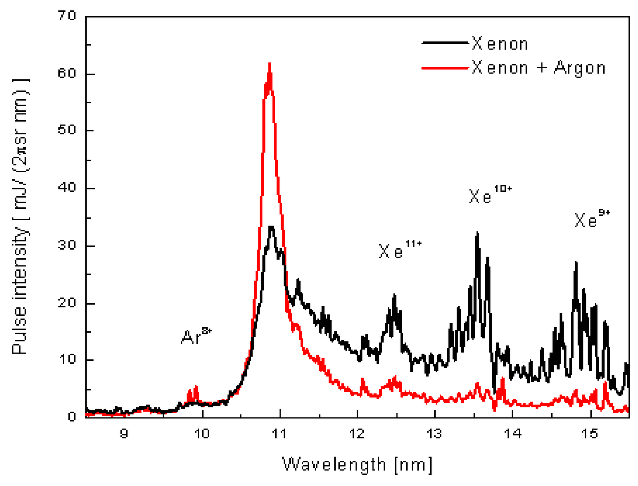
Influence of Gap to Pitch Ratio



- Peak intensity drops as the ratio of gap to pitch decreases.
- The contrast start to drop as the gap becomes wider than half of the pitch.
- Best contrast is at 1:1 line to space ratio.

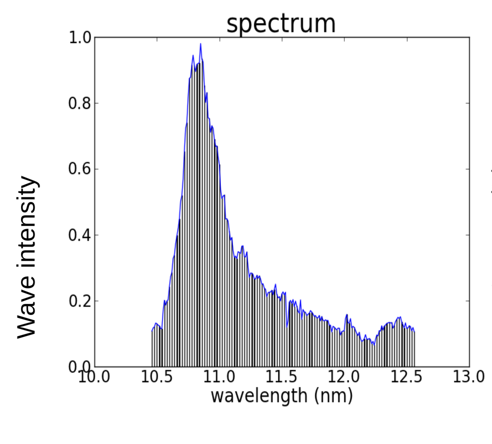
Laboratory discharge EUV source for interference lithography

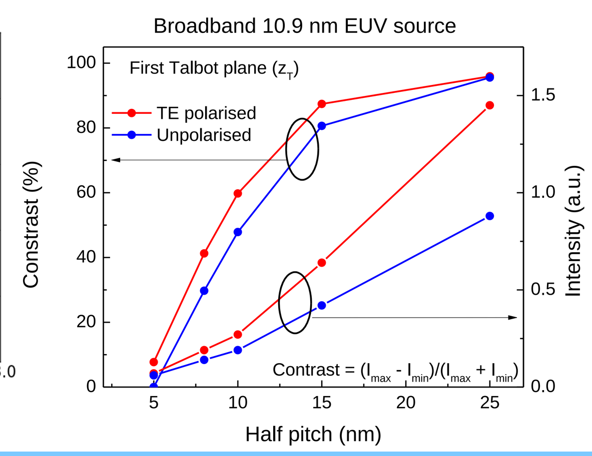
EUV source: plasma-based gas discharge EUV radiation source developed at Fraunhofer ILT
- compact 2 kHz source
- input power 5.6 kW
- pinch radius 100 µm
- 100W/(mm²sr) radiance @ 10.9 nm



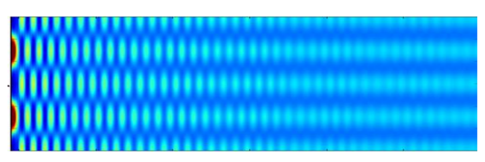
Broadband emission spectra of Xe/Ar discharge produced plasma EUV source.

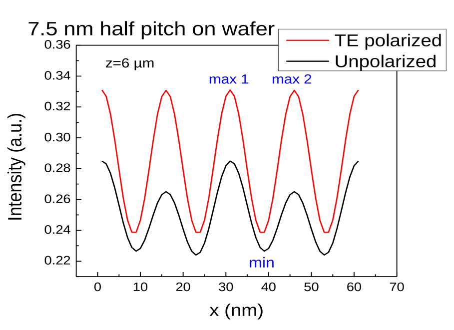
Talbot images with broadband Xe/Ar EUV discharge source



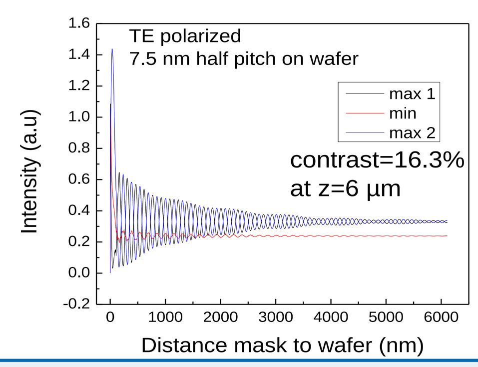


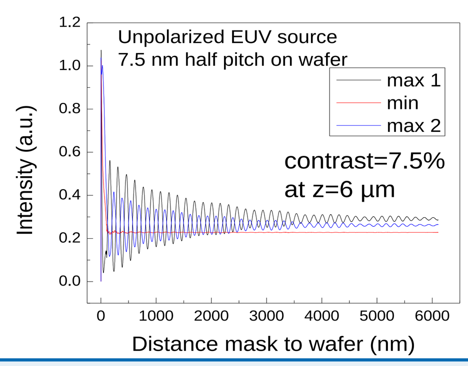
Achromatic Talbot frequency doubling



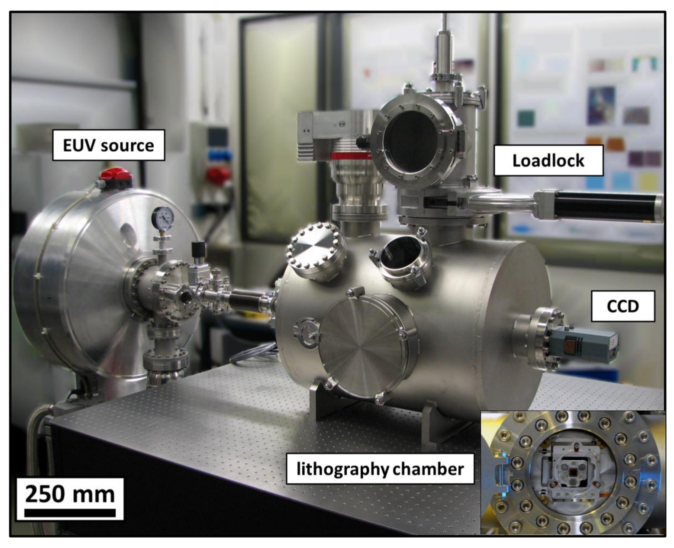


- Achromatic Talbot allows sub-10 nm patterning with 2:1 mask demagnification





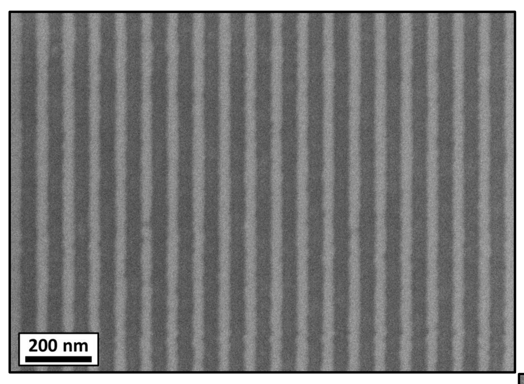
Lithography setup at RWTH/ILT



- 65 x 65 mm² exposable area
- Accepts 100 mm wafer
- Single field size > 4 mm²
- Field exposure time < 30s @ 30 mJ/cm²

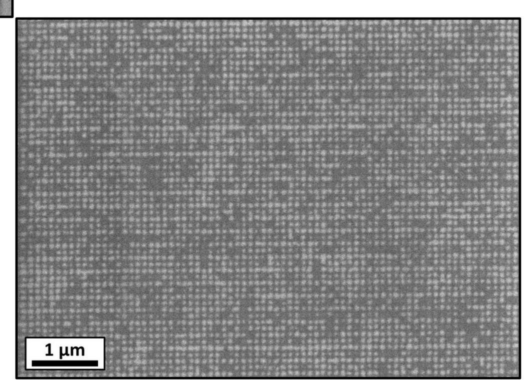
EUV-IL exposure setup with the DPP EUV source

Exposure results

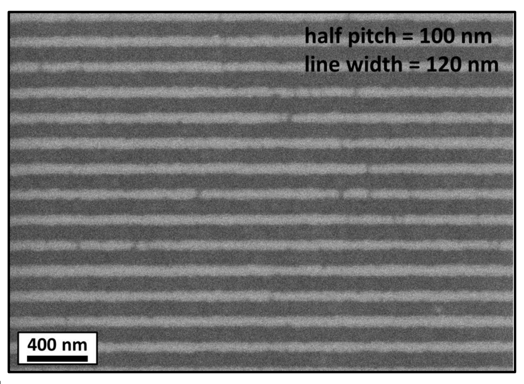


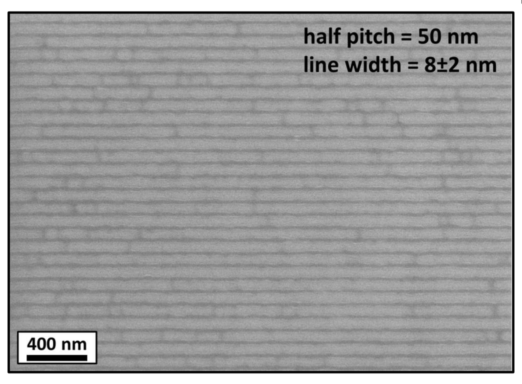
High quality 100 nm L/S array written in ZEP resist by EUV proximity printing.

The dot patterns with 50 nm half pitch written in ZEP resist by EUV-IL.



- EUV proximity lithography generates 1:1 copy of the mask, but EUV achromatic Talbot lithography leads to period and feature size reduction.





sub-10 nm structures with 50 nm half pitch obtained with EUV interference lithography with 100 nm half pitch transmission mask

Summary

- Talbot self-imaging is simulated for the EUV radiation and transmission mask for various conditions, pitch size, space to pitch ratio and polarization.
- Resolution limits for the self-imaging with monochromatic wave and Talbot image mixture with broadband EUV radiation have been explored.
- It is demonstrated that sub-10 nm patterns are possible both with monochromatic and achromatic Talbot lithography, but contrast and intensity of the images decrease significantly for half pitches below 20 nm.
- The experimental results confirm that it is possible to perform interference lithography with a laboratory scale discharge plasma based EUV source.

[1] K. Patorski, in *Progress in optics XXVII*, edited by E. Wolf, Elsevier Science Publishers, pp. 2-108 (1989)
[2] H. F. Talbot "Facts relating to optical science" No. IV, Philos. Mag. Vol. 9 (1836)
[3] Lord Rayleigh "On copying diffraction gratings and on some phenomenon connected therewith" Philos. Mag. Vol. 11 (1881)
[4] Optics Communications **180**, 199–203 (2000)